Recommendations for a Department of Energy Nuclear Energy R&D Agenda

Summary Report

INTRODUCTION

The world's energy future is dominated by global energy growth, marked by significant uncertainties and potential instabilities, and subject to increasingly important environmental concerns. Nuclear power makes important contributions to our energy supplies that can be neither ignored nor easily replaced without significant environmental and economic costs. Future reliance on these contributions requires continued progress on the issues confronting nuclear power today: safety, waste management, proliferation, and economics. A strong nuclear energy R&D program is needed to ensure this progress and to enable the U.S. government to meet its three primary energy responsibilities: (1) respond to current needs, (2) prepare the country for anticipated future developments, and (3) safeguard the country from unexpected future events.

Nuclear power plays a significant role in the U.S. economy, providing over 22% of the nation's electrical energy generation capacity while avoiding emissions of 147 million tonnes of carbon (MtC) per year. Barring unforeseen circumstances, it will continue to do so at least until the end of the licensed lifetimes of the majority of the currently operating reactors. Although construction of new nuclear power stations is unlikely under present economic and political conditions, the reemergence of nuclear power as a major contributor to the nation's well-being should be considered as the U.S. government grapples with major environmental and energy security issues.

Even if the role of nuclear power as a source for the nation's energy supply continues to diminish, the need to confront major issues associated with nuclear power will endure beyond the lifetime of the current generation of reactors.

With these realities in mind, the underlying issue is not whether to continue nuclear power or nuclear power research, but rather to determine to what extent nuclear power and nuclear power research are necessary to ensure vital national interests.

Review of the issues, scenarios, and their implications clearly indicates three major themes, or challenges, for the U.S. role in future nuclear energy activities. These challenges will become particularly difficult if the current domestic trend of a decline in nuclear power continues. These challenges are:

- ***Continuing global influence*** *on international policy in such significant areas as nuclear nonproliferation, nuclear safety, and nuclear materials management.*

- ***Maintaining technical competencies*** *to ensure long-term expertise, capabilities, and vital infrastructures as well as leading-edge R&D in nuclear safety, nuclear materials management, fuels, and advanced proliferation-resistant technologies.*

- ***Ensuring a viable nuclear energy option*** *as an effective, economic alternative to address environmental and energy security issues.*

These challenges are at the root of the U.S. government's role in nuclear power and nuclear power research. In addition, the U.S. government has the responsibility for promoting the nation's economic competitiveness. This means ensuring that the nation's energy needs, after considering all constraints and all options, can be met as productively, responsibly, and economically as possible. Since the long-range forecasting of these needs is imprecise at best, it is the government's responsibility to ensure that all viable options and strategies for a secure energy future are maintained. Therefore the government needs to preserve the nuclear option.

While there continue to be a number of uncertainties and differences of opinion about the future role of nuclear energy both in the United States and abroad, there are national security, economic, and environmental dimensions that are of primary concern. The future of nuclear energy hinges on a number of key principles, objectives, and assumptions:

- Nuclear power supplies more than 20% of the nation's electricity, and currently-operating reactors will continue to supply a significant amount for decades.

- Nuclear power reduces the U.S. emission of carbon and other greenhouse gases, currently avoiding emissions of 147 MtC each year, which is equivalent to 10% of current U.S. carbon emissions.

- Meeting U.S. electrical energy demand is critical to continued economic growth and security. A diverse set of production alternatives, including nuclear, is vital to the national interest in the mid-to-long term. Nuclear power is a domestically “independent” energy source, reliable in the event of international tension and market uncertainty.

- Programs to assure that safety, environmental, and waste management problems are solved in a cost-effective manner are essential to a viable nuclear option; regardless of the future of nuclear power, the benefits from nuclear activities over the past 50 years have left a legacy of materials, wastes, and facilities that will require long-term nuclear expertise.

- Environmental, national security, and economic developments can have short-term, substantial impact on the relative advantages of available energy sources. In particular, the environmental advantage of nuclear reactors, which do not create emissions related to greenhouse gases or acid rain, provides an essential energy resource to address environmental security issues and needs.

- Global energy demands are expected to grow dramatically, and the growth of nuclear power may be much greater in developing countries. Even in the slowest-growth projections, total worldwide nuclear generating capacity is expected to grow over the next 50 years. As has been the case during the first 50 years of the Nuclear Age, it is in U.S. national security and economic interests to maintain international leadership and expertise in nuclear energy, assuring the international community that the United States has maximum impact on the proliferation, safety, environmental, material control, and waste management aspects of nuclear developments worldwide.

- A vibrant educational infrastructure ane the maintenance of critical skills, technology, and facilities are essential to the ability of the United States to meet future national challenges, but the existing infrastructure may erode to unacceptable levels without a strong national nuclear research agenda.

- The threat of nuclear proliferation is a concern that requires significant long-term efforts, both institutional and technical, to manage effectively.

- Because of the magnitude of the consequences of a nuclear accident, and the caliber of the uncertainty surrounding the consequences, nuclear safety remains an important public concern.

- The cost of generating domestic nuclear power currently is unacceptably high relative to the major alternatives.

It is imperative that the objectives, policies, and R&D programs for nuclear power be developed in such a way as to exploit the benefits of nuclear power and minimize the disadvantages as they relate to important national goals.

Safety, security (i.e., safeguards, security, and proliferation concerns), waste management (including disposal), and cost are the prime factors affecting public acceptance of nuclear power as part of the U.S. energy program. These factors have been of concern since the beginning of the peaceful use of the atom. For the past 40 years, the relative importance of these factors has changed to reflect social, economic, and political realities of the times. The U.S. nuclear energy program's issues and goals must be defined in order to identify what policies and research will be necessary to support the program; the objectives of such a program; and, in addition, the major concerns of the U.S. government, the utility industry, and the general public that might affect this program.

This report, along with its attendant appendices, offers recommendations for a future nuclear energy research and development program that will meet the major challenges facing the United States' energy future, and ensures that the United States' vital nuclear requirements are satisfied even in the event of unlikely future scenarios.

Appendix 1 reviews historic and current U.S. nuclear policies and objectives to identify those national and international issues both influencing and affected by nuclear energy and nuclear energy R&D. Substantively, this review shows the need for maintaining nuclear power as an energy option for the future, and reinforces the global importance of nuclear issues.

Appendix 2 examines the current national nuclear energy R&D program. A review of this work shows viable programs in many of the issues facing nuclear energy today; however, a number of new research topics (summarized in the section on recommendations) must be addressed to prepare the United States for the potential realities of tomorrow.

Appendix 3 provides an overview of the issues involving nuclear power today, ranging from energy and environmental security issues to nuclear proliferation and the economics of nuclear power. Although many of the challenges to nuclear power are institutional (including the continued perception of risk associated with nuclear proliferation, waste and spent-fuel management, and nuclear safety), there are major contributions that technology development can make in each of these areas.

Appendix 4 evaluates several alternative nuclear futures, both domestic and foreign, and uses them to illustrate the implications of these futures on the various issues to help define appropriate U.S. responses, objectives, and nuclear energy R&D support. The major challenges to U.S. interests will occur if the United States chooses, or allows, the abandonment of nuclear power.

Appendix 5 summarizes the discussions from Appendix 4 and reviews the implications of both the alternative nuclear futures and the R&D requirements relative to the issues outlined in Appendix 3. This analysis helps to reinforce the cross-cutting implications of the R&D programs throughout the various issues and shows how, even under the most pessimistic assumptions, there is a vital need for continuing technology development for nuclear power.

Appendix 6, the final appendix, summarizes the recommendations with respect to the potential nuclear futures. Here, the potential futures are shown as evolutionary in nature, and the R&D requirements are supportive of each other.

PERSPECTIVES

The future of nuclear power generation in this country and abroad is at a critical point. Although a competitive alternative, nuclear power has insufficient political and public acceptability in many countries, including the United States, to support the substantial economic and social costs of increased reliance on its use. Increasing emphasis on short-term energy economics is undermining the long-term economic advantages of nuclear power. The broad energy picture (i.e., supply and demand, domestic and international) is in a state of conditional stability (i.e., at saddle-point). Energy prices and supplies are reasonably stable, and demand growth is generally under control. However, population pressures and the industrialization of developing countries are leading to significant new energy demands in the coming decades. These pressures, along with the increasing environmental, economic, and geopolitical concerns related to burning fossil fuels, will contribute to increased demand for new nuclear power technologies and greater generating capacity.

Worldwide Energy Perspectives

Historic trends in the world's population and energy use during the past century show dramatic increases in both. The beginning of the century saw a world population of approximately 1.5 billion; it is now quickly approaching 6 billion. Energy use is increasing at an even more rapid rate. As late as 1950, the world's annual consumption of primary energy sources barely exceeded 100 exajoules (1 EJ=10^{18} joules). Today, it is on the order of 400 EJ per year. Although various projections of population and energy growth vary, even the slowest growth scenarios offer exceptional challenges for the future, as Fig. 1 shows. By 2020, the world's population is expected to reach at least 7.5 billion and to consume energy at a rate of between 600 and 750 EJ per year.

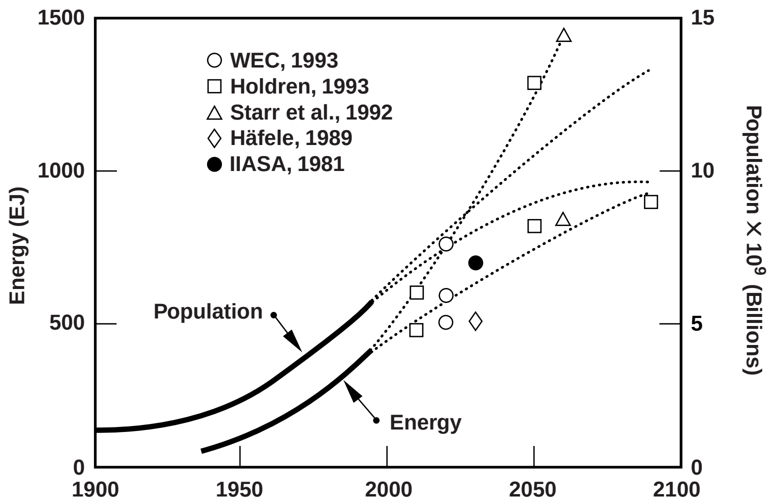

Figure 1. Actual (to 1996) and projected global population growth and energy usage.[1]

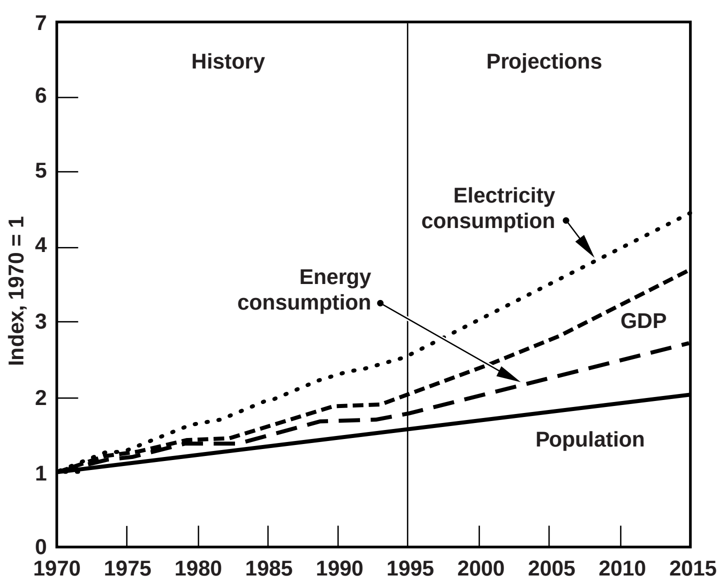

Figure 2. World energy trends showing increasing share of electrical energy consumption.[2]

[1]Energy scenarios encompass high and low ranges and are from: World Energy Council (1993) for 2020 (three cases—high growth, reference, ecologically driven); Holdren (1993) for 2010, 2050, and 2090; Starr et al. (1992) for 2060; Hafele (1989) for 2030; and IIASA (1981) for 2030. The World Bank estimates (1994) a population of about 11 billion in 2100. Low energy estimates assume, among others, continuous energy efficiency improvements on the order of 50% by 2100.

[2]U.S. Energy Information Administration, 1997.

Electrical energy consumption is expanding much more rapidly than total energy use. As Fig. 2 shows, from 1970 to 2015, the Energy Information Administration (EIA) projects worldwide consumption of electricity to increase more than four-fold, while total energy consumption increases “only” about 2.5 times. This trend is even more dramatic among the developing countries, where total energy consumption for the same period is expected to increase more than six-fold, but electrical consumption is expected to increase more than fourteen-fold.

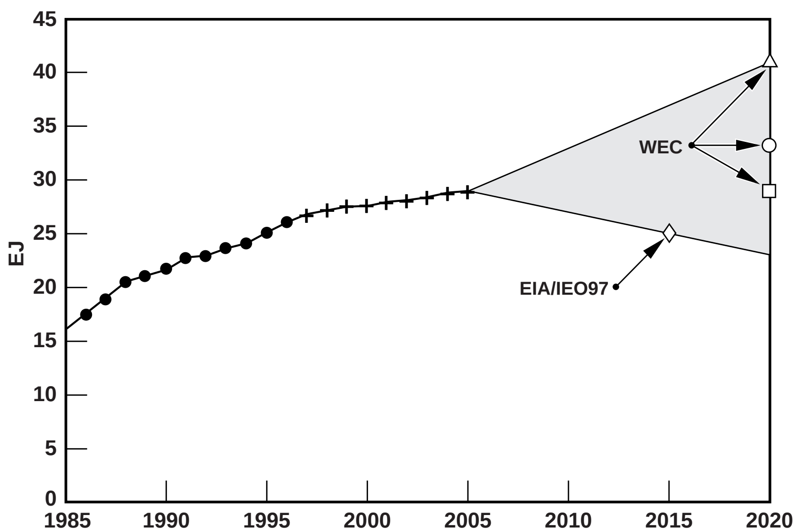

Figure 3. Actual (to 1996) and projected global nuclear generating capacity (EJ/year).[3]

Projections for the future use of nuclear power vary greatly, but most show significant growth in the consumption of nuclear power everywhere except in the United States. Globally, most projections show slight-to-moderate growth for nuclear power use, but include projected declines in U.S. domestic nuclear power generation. Figure 3 summarizes the historic capacity, capacity under construction, and projections for global nuclear energy consumption through 2020. The only example suggesting a global decline in nuclear energy use is the International Energy Outlook (IEO) 1997 reference case,[4] which

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[3]Actual data are from British Petroleum (1997). Projected points to 2005 are estimated nuclear power additions (under construction and on order) from *Nuclear News*, 1997. The 2015 point is EIA reference scenario (1997) and assumes phasing out of U.S. nuclear power plants with no life extensions resulting in net global loss in spite of the growth of nuclear power in Asia. The 2020 scenarios are from the World Energy Council (1993) and are projected nuclear energy sector contributions to the three WEC energy scenarios shown in Figure 1.

[4]For the United States, the reference case assumes that most reactors will be retired when their licenses expire, as defined by the U.S. Nuclear Regulatory Commission. Also, reactors whose current operating costs exceed 4.0 cents per kilowatt-hour are assumed to be shut down 10 years

projects the decline of nuclear capacity from 344 gigawatts (GWe) in 1995 to 332 GWe in 2015, primarily because nearly one-third of the present U.S. nuclear capacity (100 GWe) is scheduled for retirement by 2015. Although not enough to offset planned retirements, significant increases in nuclear capacity are projected for developing countries, including an additional 31.5 GWe by 2015 in China, South Korea, India, and Taiwan. This geographic region has the highest rate of growth in electricity demand in the world and is therefore in need of extensive baseload capacity additions. Current and projected regional distributions of nuclear generating capacity under this scenario are summarized in Fig. 4.

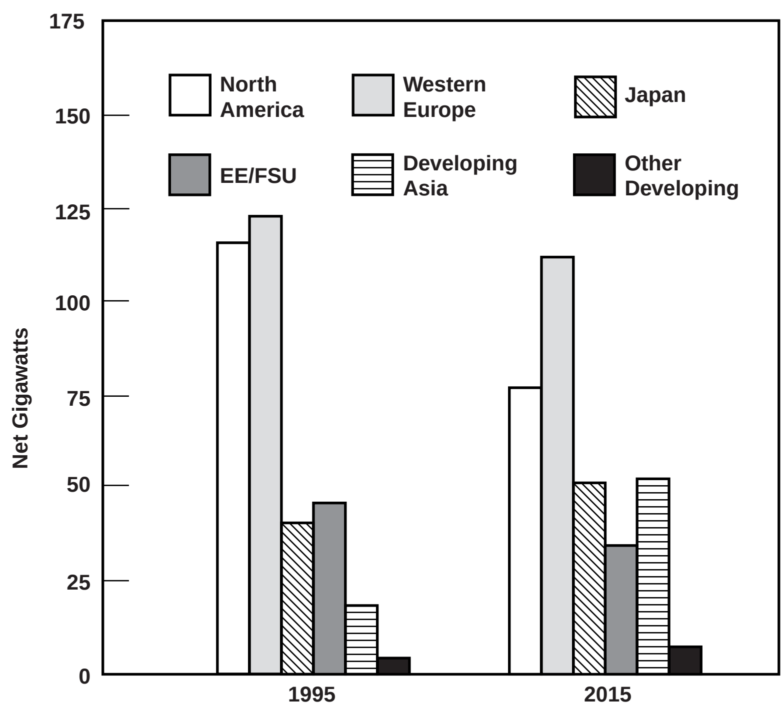

Figure 4. World nuclear energy capacity by region in 1995 and 2015. [5]

The EIA high-growth case projects nuclear power generation to increase from the 1995 capacity of 344 GWe to nearly 450 GWe by 2015. This high-growth case projects only a small decline in domestic U.S. nuclear capacity (from 100 to 95 GWe) over this period but a substantial growth in nuclear capacity essentially in all other parts of the word: nuclear power in the rest of the industrialized countries grows from 178 to 212 GWe; Eastern Europe and

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before their license expiration dates. For foreign nuclear projections, the reference case reflects fairly conservative estimates of completion dates for units under construction and of retirement dates.

[5]International Energy Outlook, U.S. Energy Information Administration, 1997.

former Soviet Union (FSU) from 46 to 66 GWe; the developing countries from 21 to 77 GWe.

Much attention has been given to the anticipated retirement of aging and uneconomic nuclear plants and the adverse impact that replacing these plants with fossil-fueled plants would have on carbon and greenhouse gas emissions. In addition to the 38 GWe of retired domestic nuclear capacity in the AEO97 case,[6] the EIA anticipates that 71 GWe of fossil generation will also be retired by 2015. Combined with the new growth demand, a total of nearly 320 GWe of new generating capacity will be needed by 2015, representing construction of nearly 1100 gas-fired generating plants or more than 50 plants per year. Considering sensitivities to carbon emissions, implications of deregulation, and costs and delays that may result from local opposition to new plant construction, extending the life of existing nuclear power plants could be most advantageous in assuring a stable and reliable electrical supply system.

Time-frame

Many of the issues surrounding nuclear power are long-lived. The average plant lifetime is on the order of 30 years. Nuclear waste has a very long life. Because of these long time-lines, there is a tendency to focus on the longer term and to treat nuclear power primarily as an option for the future.

However, if one looks at the current situation, there are a number of features that will become increasingly important earlier on:

- Aging of the current nuclear power fleet, with early retirement of some units, will soon exacerbate the energy supply / demand balance.

- Increased environmental, CO_2, and global warming concerns are increasing the demand for fossil fuel-free energy sources.

- The desire and / or need for nuclear power is increasing among the developing countries, particularly in Asia.

- Civil stocks of plutonium, particularly as separated material but also in spent fuel, are increasing, and with a continued imbalance in mixed oxide (MOX) utilization likely.

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[6]Annual Energy Outlook, U.S. Energy Information Administration, 1997.

- Uranium is inexpensive, a situation exacerbated by excess weapons material supplies.

- There is a near-general consensus that breeders are unnecessary in the next few decades.

- There is a critical decline in nuclear engineering university programs and enrollment.

- The domestic industrial base for nuclear power is eroding rapidly in the United States, and even optimistic demands for new nuclear capacity may be insufficient to maintain vital capabilities.

All of these issues presently affect the status of nuclear energy, and pressures from them will increase in the near future. Current trends do not promise solutions within the next two decades.

The Role of DOE and the U.S. Government in the Development of Nuclear Power

The U.S. government's role in energy development has three primary responsibilities: (1) respond to current needs, (2) prepare the country for anticipated future events, and (3) safeguard the country from unexpected future events. The United States' and the world's energy demands are changing (even though energy prices have remained stable). Environmental issues, continuing world development, and changing demographics threaten the U.S. energy status quo. In the future, global energy growth is certain, and increased competition for energy resources is anticipated. The need to ensure a diverse spectrum of flexible environmentally and economically acceptable energy options in such an anticipated future is unquestionable. Because nuclear power's potential role in mitigating important environmental concerns while ensuring energy security has broad implications and impacts, it is in the nation's interest and the government's responsibility to ensure the development of technical solutions to the impediments to future implementation of nuclear power.

The role of DOE (and its predecessors) has changed dramatically from that of the early days of the Atomic Energy Commission (AEC). Although now a substantially mature industry, the nuclear industry does not have the resources to meet all the demands society places on it, and many of the country's energy demands are far beyond the abilities of any single energy industry to overcome. These significant technical challenges affect the entire society, and DOE has responsibilities for meeting many of these challenges.

It is not always easy to distinguish the role of the government from the responsibilities of industry. The *cost* of nuclear power is an industry problem and responsibility. The *economics* of electrical power, in general, and the impact of nuclear power costs on national energy economics are issues of importance to the U.S. government.

One of the roles of government R&D is to stimulate private R&D investment in areas of national importance. This is a significant challenge in an economic environment of generally shrinking R&D budgets. It is even more difficult, if not crucial, in the nuclear environment where future domestic development and implementation is in doubt, and where internationally domestic corporations are losing ground to foreign competition.

Rapid movement toward deregulation of the electric utility industry is presenting a significant challenge to both the industry and the government's role in overseeing the industry. Premature shutdown of nuclear plants (i.e., prior to construction of adequate alternative energy sources) will place the country's electrical supply system in a potentially precarious state. Although substantially independent for our electrical energy requirements, portions of the country's electrical grid are at or beyond capacity (as evidenced by massive power failures in the Northeast) and are increasingly dependent on imports of power from Canada. The recent decision by Ontario Hydro to suspend operations at seven of its CANDU reactors, even as it was attempting to increase electrical sales to the United States, will likely have a significant effect on power availability in the Northeast.

Nuclear Energy Futures

Current energy trends, if continued, suggest that the United States is heading toward a *gradual abandonment* of the nuclear power option. However, growing concern over emissions of carbon dioxide and other greenhouse gases is creating pressure for a continued reliance on nuclear power in the United States, and the *reemergence* of nuclear power as the preferred option for new generating capacity could be possible in the future. These alternative futures, or scenarios, are not entirely mutually exclusive. As the various societal issues and forces change with time, the constraints and incentives affecting the nuclear power option may change, resulting in one scenario phasing into another over time.

The alternative U.S. nuclear energy futures, and the implications of those futures, are closely tied to the alternative futures for nuclear power internationally. Internationally, nuclear power generation is likely to experience either *growth* or *decline*. It is, of course, possible that globally nuclear power may maintain its current share of electrical generation. However, the implications of the international nuclear market on U.S. policy and R&D options are sufficiently constrained by these two limiting cases. Thus, we will consider the implications of U.S. options in the face of these two international frameworks.

NUCLEAR ENERGY POLICIES

U.S. nuclear energy policy is strongly influenced by many issues. Nuclear energy can and does play a major role in domestic energy security, but the potential for misuse of fissile materials (particularly separated plutonium) for weapons applications raises concerns of nuclear proliferation. Thus, although U.S. nuclear energy policy is primarily formulated as part of the nation's overall energy policy, it is affected by other U.S. policies, such as those for defense and the environment, and by international obligations.

The Atomic Energy Act (AEA) of 1946 (as amended) defines the government's role (through the then Atomic Energy Commission) in the development of nuclear power. Although its role has been modified and diluted over the years through various acts and directives, the underlying DOE responsibilities for ensuring the development of safe, secure, and environmentally-sound nuclear power have never been fundamentally altered.

The major modifications to DOE's responsibilities for nuclear power reflect the concerns of the times. The AEA stressed the importance of developing safe atomic energy for peaceful uses and the need for international cooperation. The Nuclear Nonproliferation Treaty (NPT) of 1968 and the Nuclear Nonproliferation Act of 1978 emphasized the growing concerns surrounding the threat of nuclear proliferation and the need for fissile materials safeguards. Concerns of proliferation and the increased needs for effective safeguards and security were again emphasized in the recent Presidential Decision Directive (PDD-13) of 1993. The Nuclear Waste Policy Act (NWPA) of 1982 focused on the importance of effectively dealing with nuclear waste and spent nuclear fuel and obligated the government to accept responsibility for commercial spent fuel disposition. The Energy Policy Act (EPACT) of 1992 reaffirmed the importance of dealing with waste and spent fuel issues, focused on long-term development of nuclear power options, and recognized the growing maturity of the U.S. nuclear industry in requiring non-federal matching funds for a broad class of demonstration and commercial applications projects.

Nuclear energy is specifically mentioned in the National Energy Policy Plan of 1995 as one of the elements of a balanced domestic energy portfolio. According to the plan, the Administration's nuclear energy policy is:

- *To maintain the safe operation of existing nuclear plants in the United States and abroad, and*

- *To preserve the option to construct the next generation of nuclear energy plants.*

This commitment to nuclear power as a viable option for the United States is reaffirmed in the 1997 DOE Strategic Plan:

> *"By resolving nuclear waste disposal issues and developing advanced nuclear technology, DOE will remove some concerns and may open the door to renewed consideration of nuclear energy as an additional option for addressing air quality and greenhouse gas emissions."*

The 1997 DOE Strategic Plan also reaffirms DOE commitments to international nuclear cooperation and markets, to nonproliferation, and to defense applications of nuclear power technologies.

CURRENT NUCLEAR ENERGY R&D

Just as nuclear energy policies have changed over the past five decades, the type and sponsorship of nuclear R&D have also changed over time. Early nuclear energy research focused on the development of nuclear power systems for commercial application, largely utilizing technologies developed for naval propulsion applications and funded substantially by the U.S. government through the AEC. In the late 1960s and through the 1970s, energy security issues led to major developments of breeder reactor technology and improvements in light water reactor (LWR) safety, funded primarily by the government combined with large-scale commercial reactor development substantially developed by industry. In the late 1970s and early 1980s, reactor orders declined and earlier orders were canceled, commercial reactor development slowed down, and both industry and government funding concentrated on continuing safety improvements, which gained importance following the events at Three Mile Island and Chernobyl.

Today, both the scope and funding of nuclear energy research have declined. Most of the R&D on nuclear power topics is performed by “four” organizations: DOE, the Nuclear Regulatory Commission (NRC), the Electric Power Research Institute (EPRI), and various “industry groups” (including fuel vendors and reactor owners’ groups). Each of these organizations has unique interests, time scales, and goals with little overlap among the various organizations.

DOE generally sponsors a few large programs having significant impact on the long-term use of nuclear power in the United States. The last major reactor development program (the Advanced Light-Water Reactor program) is nearly complete. Other DOE programs focus on the international nuclear reactor safety aspects and the development of the MOX alternative for disposition of excess weapons plutonium.

The NRC focuses on many smaller projects organized around safety-related technologies and phenomena. This research aims to advance the state of the art and to ensure that the NRC has the technical capabilities to make authoritative judgments related to the licensing and safe operation of nuclear power plants.

EPRI concentrates on issues affecting plant performance and operations through a large number of small, short-term projects. Some of the issues pursued include fuel reliability and storage, chemistry and radiation control, component reliability, and cost-control technologies.

Industry groups concentrate primarily on fuel performance and reliability improvements; on component aging, reliability, and replacement; and on plant operations and procedures.

BENEFITS AND RISKS OF NUCLEAR POWER

Nuclear power is considered an important, and sometimes contentious, national issue because it has both risks and benefits, just as any other technology. Unlike some national issues, however, there are important risks that will accrue if the nuclear power option is abandoned. Some of the major benefits of nuclear power are:

- It is a significant, stable, and independent domestic and international energy resource, offering needed diversity and flexibility against future uncertainties.

- It is safe and environmentally sound, emitting few pollutants and no carbon or other greenhouse gases.

- It is an important source of U.S. high-technology exports, and foreign demand for such exports is increasing.

- It helps the U.S. maintain positions of technical leadership and influence in important international policy areas, such as nonproliferation, safety, and waste management.

There are, of course, risks associated with nuclear power:

- International proliferation implications and risks continue.

- Spent fuel and waste management are critical issues.

- Nuclear safety remains a significant issue.

- Nuclear power's cost is currently high relative to most alternatives.

Just as there are risks associated with nuclear power, there are risks associated with *not* exploiting nuclear power:

- Loss of international influence and technical leadership.

- Erosion of critical infrastructures necessary to effectively deal with significant nuclear issues, including R&D, waste management, and nuclear facility safety.

- Impairment of energy options and flexibility.

If the United States plans to meet its international environmental commitments, support a growing economy, and ensure its own as well as others' energy security, it should find ways to enhance and support nuclear energy as a part of the U.S. energy portfolio. The significant energy security and environmental benefits of nuclear power will only be realized if the undesirable risks associated with nuclear power are reduced. These risks can be reduced by well-focused R&D.

In light of major uncertainty for the world's energy outlook and markets; of clear needs for facilities and expertise to deal with existing and future security, safety, and environmental issues; and ofcontinuing international tension in much of the world, the United States simply cannot afford to allow its nuclear influence, infrastructures, or options to erode further.

Even if the current generation of domestic nuclear power is allowed to decline as a national resource, the United States is faced with the task of mitigating a clear set of unacceptable risks and addressing the related major challenges. These challenges will also require specific R&D efforts to reduce these unacceptable risks.

KEY ISSUES FOR NUCLEAR ENERGY R&D

The four most visible issues associated with nuclear power (economics, proliferation, safety, and waste management) are only a subset of broader issues of national importance. Vital national issues affecting or affected by nuclear energy R&D can be lumped into three broad categories:

- National security (e.g., nuclear nonproliferation).
- Environment, safety, and health (including nuclear waste management).
- Economic competitiveness (e.g., maintaining the nuclear infrastructure).

Each of these areas encompasses a variety of issues and concerns, although the perspectives from which these issues are viewed vary widely. It is also clear that the various perspectives will change with time, and there are other considerations that affect nuclear energy policy, such as public perception and international obligations.

Each of these issues has implications for both policy and technology and can be addressed, at least in part, through R&D and technical innovation. DOE policies and R&D objectives must have one common characteristic: They must contribute to, or further, a set of "enduring objectives" for the overall U.S. nuclear policy. These objectives are embodied in the following broad issues.

National Security

National security encompasses three principal issues: (1) nuclear nonproliferation, (2) energy security, and (3) national defense.

Nuclear nonproliferation is defined here to address proliferation, as well as theillicit procurement and use of nuclear materials from the commercial nuclear fuel cycle. Continued development of nuclear power abroad is likely, particularly among the developing nations and throughout East Asia. Such a spread of nuclear power, particularly among less affluent and less stable nations, will increase the need for a strong nonproliferation regime. Development of technologies to improve the proliferation resistance of nuclear power systems can help augment the more traditional safeguards, transparency, and physical security approaches to nonproliferation. Without U.S. leadership in technology development for enhanced security and proliferation resistance, developing countries must choose from the currently available reactor systems, and some may choose reactors having even less desirable proliferation implications.

Energy security, including global sustainability, is here considered an element of national security because of its increasing global importance. The public expects reliable energy supplies at reasonable prices, and our domestic economy and international economic competitiveness demand both. The trend toward energy-market deregulation is reducing the energy sector's resilience and increasing dependence on fossil fuels at a rapid rate, potentially at the expense of long-term sustainability. Development of energy systems less vulnerable to economic and supply disruptions can help reduce one source of international tension and enhance U.S. national security. Nuclear power has and will continue to have an important role in minimizing the U.S. dependence on fossil energy resources and assuring diversity in the nation's energy supply.

National defense relies heavily on nuclear technology for a variety of needs, from supplying the weapons arsenal to powering naval vessels and spacecraft. The coupling between civilian nuclear R&D and military applications cannot be completely severed, and indeed civilian R&D can contribute effectively to reducing the nation's weapons' legacy, as evidenced in the potential use of civilian power reactors to burn excess weapons plutonium.

Environment, Safety, and Health

The environment, safety, and health aspects include the nuclear energy issues of major importance to the general public today. Nuclear energy continues to be the only sufficiently mature technology having *environmental benefits* for the reduction of acid rain, greenhouse gases, and global warming in the near future. Continuing public concerns about the potential health impacts of radiation lead to demands for further improvements in *nuclear safety*, both technically and culturally. Visible progress in *waste management*, particularly in spent fuel disposal, is necessary to reinstill public and industrial confidence in federal energy management.

Environmental benefits of nuclear power as a tool in the fight against increasing greenhouse gas emissions are clear, and nuclear power continues to have great promise for reducing society's adverse impact on environmental issues. Nuclear power plants are currently displacing some 147 MtC of carbon emissions per year in the United States and some 500 MtC per year worldwide. Nuclear power plants do not emit volatile organic compounds, nitrogen oxides, carbon monoxide, particulate matter, and sulfur dioxide, all of which come from fossil fuel combustion and have significant health impacts on the public. On the other hand, even though nuclear waste issues appear technically solvable, the apparent inability to resolve nuclear waste political issues will continue to slow public acceptance of nuclear power.

Nuclear safety is perceived as one of the most important issues affecting nuclear power today. Although western reactors are actually quite safe, the graphic events at Three Mile Island and Chernobyl have perhaps irreversibly altered public perception of the risks associated with nuclear power and have made safety an enduring nuclear issue. The consequences of another nuclear accident such as Chernobyl could lead to demands for termination of the world's nuclear generators, and could potentially eliminate the nuclear option for decades to come.

Waste management, particularly that of spent fuel, is one of the dominant concerns the U.S. public has regarding continued use of nuclear energy. Although technical solutions to effectively deal with nuclear waste appear available, the institutional issues are proving particularly difficult. The federal government is having difficulty meeting its statutory responsibility to manage the spent fuel from the nation's commercial nuclear power plants. Utilities, electricity customers, and state leaders are increasingly frustrated by government inaction on the spent fuel disposal program. The task of nuclear waste disposal has been made much more difficult by uniquely stringent standards for proving the safety of the repository. Concrete progress in the management and disposition of all forms of nuclear waste is an essential element for the future of nuclear energy in the United States, and ultimately in the global community. One subject particularly important to waste management, but common to all nuclear environment, safety, and health issues, is the definition of acceptable lower limits of radiation content and exposure, i.e., the definition of an acceptable minimus.

Economic Competitiveness

Economic competitiveness is an increasingly important issue in an increasingly global economy. International power and influence are ever more closely coupled with economic strength and competitive advantage in the marketplace. Both our domestic standard of living and our ability to compete internationally are dependent on favorable energy *economics*. The U.S. ability to affect foreign nuclear policy will depend substantially on U.S. involvement in the nuclear markets, and the economic competitiveness of the domestic U.S. nuclear energy *infrastructure* is synergistically linked to our foreign competitiveness and influence.

Economics of nuclear power in a changing domestic energy market is an increasingly important issue. The ability of nuclear power to compete domestically with other alternatives is dependent on a fair and equitable economic playing field, and on nuclear energy's ability to fulfill cost and schedule promises.

Infrastructure is the basis of the U.S. nuclear capability, and it is in serious jeopardy. Overall economic competitiveness of U.S. nuclear energy depends on the maintenance of this capability and underlying infrastructure. Even in a future with dwindling domestic nuclear power, much of the existing infrastructure will be needed to ensure safe operation of remaining facilities and to deal with the long-term waste management issues resulting from both nuclear power and defense activities.

Enrollment in nuclear engineering nationally is declining, nuclear engineering departments are being dissolved or absorbed into other departments, and faculties are dwindling. This problem is exacerbating the deterioration at the national laboratories, where the workforce and many facilities are aging and important capabilities are diminishing. Serious efforts to address these declines are necessary.

Other Considerations

Other considerations affecting nuclear energy include the government's need to adhere to international agreements, public acceptance of nuclear energy, the regulatory environment, and the future role of DOE.

International obligations and international relations affect the government's responsibilities for nuclear energy and nuclear research and development. As one example, disarmament and resulting fissile materials disposition rely on technologies and existing and in-development infrastructures to accomplish goals set by international accords. The United States views the nuclear fuel cycle quite differently than other countries do, citing proliferation and economic issues as overriding, while others place higher value on energy security and believe that the U.S. position contributes to growing plutonium inventories and that plutonium recycling is an effective path to nonproliferation by limiting stockpiles of plutonium. What are the conditions under which these views might change? Under what conditions might the United States find itself needing to reopen fuel cycle R&D? What are the likely or potential time frames, and what do we need to preserve for that eventuality?

Public perception of nuclear energy relies on satisfactory progress in issues already discussed, and on proactive and overt steps taken to communicate with and involve the public on important nuclear matters. Most important, the public must see the DOE and the nuclear industry as being truly responsive to its needs and concerns. Even if nuclear power is to emerge clearly as a technology of choice for future energy needs, implementation of future nuclear technologies will not be possible without public acceptance of nuclear power.

The regulatory environment, even with recent advances, will require additional reform for nuclear power to continue to play a major role in the U.S. energy future. Regulatory uncertainties and delays must be further reduced. Regulations must be sufficiently flexible to adapt to new safety technologies without major disruptions to existing systems and infrastructures. Many current regulations are unnecessary, and others inadvertently serve to reduce real safety. These need to be thoroughly reviewed and modified or dropped as appropriate.

The role of the U.S. government, and of the Office of Nuclear Energy, Science and Technology (NE) in particular, in the continued development of nuclear energy and the balance between federal and industry funding of nuclear energy R&D are under serious debate. Perhaps even more basic is the question of what *should* the role of nuclear power be over the next 20–50 years, and how can DOE help realize that role? Can nuclear power reemerge as part of a bold energy plan in the next decade(s), or is it rather an "insurance policy" for the future or relegated to a vanishing role? In any case, what are the policy and R&D requirements?

CHALLENGES FOR NUCLEAR ENERGY POLICY AND R&D

The options and objectives for nuclear energy policy and R&D depend strongly on the future of nuclear power both here and abroad. The current trend in the United States is toward a *gradual abandonment* of nuclear power. However, a number of pressures and issues exist today, including environmental quality and energy security, that may result in a national need for *continued reliance* on nuclear power as a major contributor toward mitigating these issues. Although a *reemergence* of nuclear power as the preferred option for new energy generation in the United States currently appears to be only a long-term prospect, an uncertain outlook for alternative energy sources, coupled with certain global population and energy growth, make the maintenance of the nuclear option a necessary objective.

These three domestic nuclear futures, or scenarios, will exist within a global nuclear future in which nuclear power either *grows* or *declines*. The current trend of nuclear power strongly suggests global growth, particularly in the developing countries and East Asia. Although some local or regional declines are likely, and some short-term declines in global nuclear energy generation may occur—and barring another major nuclear accident or other unforeseen circumstances—a long-term global decline in nuclear energy generation appears unlikely.

Of the six possible combinations of domestic and international nuclear futures, the current trend—domestic *abandonment* of nuclear power in the face of global *growth*, and domestic *continued reliance* on nuclear power coupled with global *growth*—appears to be the most likely future and represents the major challenge to U.S. policy and R&D requirements.

Abandonment of nuclear power in the face of global *growth* represents the most difficult scenario for the United States internationally, and places critical nuclear infrastructures and expertise in serious jeopardy. Although common to all nuclear futures, this current trend presents the United States with three very difficult challenges:

- *Global influence:* How does the United States best influence the rest of the world in critical nuclear issues such as nonproliferation and nuclear safety?

- *Technology Leadership:* How do we maintain sufficient long-term expertise, capabilities, vital infrastructures, and leading-edge R&D in nuclear safety, waste management, fuels, and advanced proliferation resistant technologies to deal with the enduring nuclear legacy and to meet statutory requirements, both domestically and internationally?

- *Vital energy options:* Can the United States truly afford to preclude the use of nuclear energy in a future with unclear environmental and energy security issues?

These challenges will persist far beyond the eventual closure of the last U.S. nuclear plant under this pessimistic scenario. Meeting these challenges will require both domestically- and internationally-focused efforts. Domestically, significant continuing research is needed in safety, waste management, and spent fuel minimization; and real efforts are needed to focus on infrastructure maintenance, including efforts to maintain critical educational and research resources. Internationally, focus on proliferation-resistant reactor development, integration of entire nuclear fuel cycles, and fuel cycle safety and security will be critical to maintaining U.S. influence in these enduring areas.

A nuclear future in which the United States continues to rely on nuclear power for its electrical generating capacity is possible, desirable, and reasonably achievable. Furthermore, that nuclear power capacity will generally experience international growth.

Under this scenario, additional efforts to improve the proliferation, safety, and waste management regimes are absolutely necessary to maintain the nuclear option and ensure the ability to continue domestic reliance on nuclear energy. Improved waste minimization and waste management technologies, the continuation of safety enhancements of existing reactor designs and operations, and continued regulatory reform are critical toward maintaining the domestic nuclear option. Internationally, increased concentration on proliferation-resistant fuels and reactor technologies for implementation in developed countries and on better integration and proliferation resistance of the fuel cycle for large-scale reactor systems domestically and in the developed countries is needed.

These two scenarios are not independent futures. Since the current trend is toward a domestic abandonment of nuclear power, a continuing decline of nuclear power in the United States is expected. Thus, the challenges presented by that scenario already exist and must be addressed. Meeting these challenges will help form the foundation for the second scenario and help preserve the nuclear option.

RECOMMENDATIONS

The United States' and the world's energy environments are changing, even though energy prices have remained stable. Environmental concerns, especially growing carbon emissions, increasing world development, and changing demographics, threaten the U.S. energy status quo, and steps must be taken to address these changes. Although the global population growth rates are uncertain, future energy growth is certain, and competition for energy resources is anticipated. The need to ensure environmentally and economically acceptable energy options in such an anticipated future is unquestionable. The U.S. government's role in energy development has three primary responsibilities: respond to current threats, prepare the country for anticipated future events, and safeguard the country from unexpected futures.

Independent of what the future may hold for nuclear power development in the United States or abroad, we must maintain the nuclear option to meet current and unanticipated national needs, maintain our vital nuclear infrastructures and technology leadership, and improve our international standing and influence in global nuclear issues. Many of the issues underlying these challenges require technical solutions that can only be achieved through concentrated R&D efforts. In particular, long-term progress is needed to continue improvements in safety and proliferation resistance and improvements in waste and spent fuel management. In the shorter term, assurance of continued safe operation of existing facilities is paramount. The program outlined here addresses the significant challenges posed by the current trends in the U.S. nuclear energy picture. Each element of this program contributes to the challenges.

(1) Nuclear Energy Research Program. Create a comprehensive research program for nuclear energy, science, and technology to revitalize nuclear energy research at major universities and DOE laboratories. This initiative should be designed to ensure and strengthen the coupling between the creative resources of the universities and the programmatic focus of the laboratories. Programs and topics might include basic nuclear science and engineering as well as a wide range of applied topics such as fuels, materials, and novel reactor and systems designs.

(2) Nuclear Energy R&D to Meet U.S. Carbon Emissions Reduction Goals. Today's 147 MtC emissions per year avoided by U.S. nuclear power is threatened by the potential for premature plant closures. Pursuit of technologies for both Life Extension and Generation Optimization (LEGO) and next-generation nuclear power would continue current nuclear

greenhouse gas emission reductions and enable additional reductions in the future. R&D into monitoring, diagnostics, computing, and materials technologies is needed to help the U.S. avoid the premature closure and decommissioning of its operating nuclear reactor fleet. Successful development and use of more efficient and cost-effective nuclear power technologies that address the goals of safety, efficient resource utilization, and waste management could also have a major impact on global carbon emissions.

(3) Enhanced Proliferation Resistance. Because of the projected spread and increase of nuclear energy internationally and future uncertainties associated with world events, it is prudent for the United States to reinvigorate efforts to explore more proliferation-resistant forms of nuclear energy. Development of technologies contributing to the proliferation resistance of reactor fuels and systems, possibly including small, lower-power reactor systems designed for export to developing countries, accompanied by continuing development of improved international safeguards and security systems and regimes, could substantially improve the U.S. position and influence in international nuclear markets and nuclear decision-making processes and maintain critical domestic skills.

(4) High-Efficiency Nuclear Fuel. Cooperative development with industry of improved fuels with extended burnup, demonstrated safety margins, and the capacity to enable longer operating cycles may reduce the government's costs for spent fuel disposition and improve nuclear plant operating efficiencies.

(5) International Nuclear Cooperation will allow the United States to continue its strategy of technology and safety improvements, influencing worldwide nuclear development, and initiating international research. Nuclear safety and nuclear nonproliferation have been and are two key elements of U.S. international nuclear policy, and global collaboration is a necessity in order to preserve U.S. influence within the international nuclear community.

These research agenda are necessary to respond to the current national and global trends and to prepare for the reasonably possible futures. They also represent the minimum efforts critically necessary to enable the country to reestablish nuclear power as a viable option, should environmental concerns and energy security issues demand different options than those available today. These agenda also help guard against the consequences of less likely futures by ensuring adequate infrastructures and technical resources to maintain effective waste and spent fuel management, ensure continued safety of existing plants and facilities, manage decontamination and decommissioning of those facilities, and respond to the international imperative to effectively manage stocks of fissile materials and to avoid nuclear proliferation. Thus, even in this unlikely scenario, both the R&D and policy efforts described above will be necessary to maintain vital infrastructures and meet these global challenges.